BULLETIN NO. 650 DECEMBER, 1934

New York State Agricultural Experiment Station

Geneva, N. Y.

ZINC OXIDE AS A SEED AND SOIL TREATMENT FOR DAMPING-OFF

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PUBLISHED BY THE STATION
UNDER AUTHORITY OF CORNELL UNIVERSITY

ABSTRACT

Seed protectants, such as organic mercurials and red copper oxide, control most of the seed decay and pre-emergence damping-off caused by ***Pythium ultimum*** but sometimes fail to control the post-emergence phase adequately. A supplementary treatment for the soil surface was needed. Soluble zinc salts gave some benefit, but were too toxic to the plant. Zinc oxide used at the rate of 20 grams per square foot in greenhouse experiments with lettuce, peppers, spinach, tomatoes, and others gave satisfactory control of the post-emergence disease.

Being practically insoluble it is relatively non-injurious to plants but cannot penetrate deeply enough into the soil to stop pre-emergence decay. Hence, seeds must be treated with some protective fungicide; they must be planted as shallow as possible; and the layer of chemical around the plants must not be disturbed if zinc oxide is to give satisfactory control. Mixing zinc oxide with the covering soil is unsatisfactory because enough chemical to be effective is too toxic when in such intimate contact with the roots.

Zinc oxide may be applied to transplants on cool cloudy days, or at night, if it is washed or brushed from the foliage down to the bases of the plants. Seeds to be protected may be treated with it. It is more effective than other chemicals in some localities and for such crops as crucifers and lettuce. Zinc stearate and gluconate seemed nearly worthless as seed protectants but zinc chromate, carbonate, oxalate and powdered zinc were promising.

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THE PROBLEM

Despite years of research here and elsewhere devoted to the damping-off problem, it is still with us. New approaches, some of them brilliant, like the formaldehyde dust treatment proposed in Ohio,[1] have alleviated the difficulty somewhat, but the main problem is still unsolved. Some treatments are satisfactory in some localities, for some plants, or for some of the damping-off organisms; but damping-off still remains to plague agriculture, particularly the intensive agriculture of market and floral gardens near the large cities.

Many of the control methods evolved have proved inadequate because their fungicidal effect was too fleeting. Methods such as steaming that depend upon momentary sterilizing or pasteurizing effects frequently fail in the hands of growers because the soil becomes recontaminated later. Some case records show that damping-off has been worse after steaming soil than before.

Damping-off research at this Station has been directed toward a solution of the problem by using chemicals. Emphasis has been placed not on chemicals like formaldehyde that are soon dissipated, but on the relatively insoluble chemicals that will exert a lasting protective action as well as a momentary disinfecting action. It was difficult to find such a durable soil fungicide that was effective, and that could remain at the same time in contact with a tender seedling for long periods without injury.

Early attempts here to treat soil chemically involved applying the material to each seed thus placing it closest to the seed to be

[1] Alexander, L. J., Young, H. C., and Kiger, C. M. The causes and control of damping-off of tomato seedlings. *Ohio Agr. Exp. Sta. Bul. No. 496. 1931.*

protected. Clayton [2] and Finnell [3] pointed out the protective effect of organic mercurials on apparently "healthy" seed. Later, this idea was extended with the copper seed treatments progressing from the copper sulfate dip [4] thru copper sulfate dust,[5] to red copper oxide dust.[6] These chemicals on the seed permeate the soil around each seed and prevent much of the pre-emergence or below-ground damping-off. Frequently they give control of post-emergence or above-ground damping-off. In many cases, however, these materials do not give adequate protection against the post-emergence phase of the disease. The quantity of chemical that can be applied is insufficient. Some relatively non-injurious chemical that could be applied to the surface of the soil was needed as a supplement to the seed treatment. A "galvanizing" treatment was needed. A zinc treatment fits that idea.[7]

MATERIALS AND METHODS

The experimental technic employed has been similar to that already described in earlier publications on this subject.[8] Generally uniform weights or volumes of "healthy" seed were sown for each treatment. In these cases the average number of seeds planted was known. The soil used was always naturally contaminated with *Pythium ultimum* Trow, altho in many cases other parasitic and semiparasitic organisms also were undoubtedly present. Stand counts

[2] Clayton, E. E. Increasing stands from vegetable seeds by seed treatment. *New York State Agr. Exp. Sta. Bul. No. 554. 1928.*

[3] Finnell, H. H. Improving stands of grain sorghums by seed treatments. *Oklahoma Agr. Exp. Sta. Bul. No. 159. 1926.*

[4] Horsfall, James G. Combating damping-off of tomatoes by seed treatment. *New York State Agr. Exp. Sta. Bul. No. 586. 1930.*

[5] ————. Dusting tomato seed with copper sulfate monohydrate for combating damping-off. *New York State Agr. Exp. Sta. Tech. Bul. No. 198. 1932.*

[6] ————. Red oxide of copper as a dust fungicide for combating damping-off by seed treatment. *New York State Agr. Exp. Sta. Bul. No. 615. 1932.*

————, Newhall, A. G., and Guterman, C. E. F. Dusting miscellaneous seeds with red copper oxide to combat damping-off. *New York State Agr. Exp. Sta. Bul. No. 643. 1934.*

[7] ————. Zinc oxide as a seed and soil treatment for damping-off. *Phytopath.*, **24**: *12. 1934.*

[8] See footnote 5.

indicate the extent of seed and seedling decay below ground or pre-emergence disease. The earlier method of taking post-emergence disease readings was to wash the roots of 200 plants selected at random and determine the incidence of infection. In the tables, such records are indicated with a *d*. Later the number actually slumped over in the entire population was determined. These two methods give essentially the same results, but the latter is more rapid and perhaps gives a clearer picture. In some of the tables arithmetical averages of some of the data are given for convenience in making comparisons. Tomatoes and spinach generally were used as index plants in these damping-off studies, but the results were confirmed with others such as cucumber, lettuce, pepper, and cabbage. For reasons of labor economy much of the work was limited to the seedling tray, altho observations were made in commercial houses on transplants.

ZINC OXIDE AS A SOIL TREATMENT

As would be expected, the zinc oxide treatment was the culmination of a series of tests. Zinc sulfate was tested experimentally as early as the fall of 1929 and was used on soil in a commercial way with encouraging success in the spring of 1930 to alleviate a case of damping-off of tomatoes. Zinc sulfate-lime sprays have recently been investigated as fungicides.[9] Hartley [10] suggested that zinc chloride was valuable for controlling damping-off of conifers. It has been useful also in wood preservation and for fireblight control.[11]

Damping-off control with soluble zinc salts was variable. Sometimes it was good, as shown in Table I which gives the results of a typical test. These data demonstrate the value of the zinc ion for damping-off control. Excessive plant injury sometimes made it seem that the soluble zinc compounds increased the amount of post-emergence damping-off.

As shown in Table 1 also, the early tests with zinc oxide were not promising, not as promising in fact, as were those with the

[9] Roberts, J. W., and Pierce, L. Zinc-lime, a fungicide for the peach. *Phytopath.*, **22**: *415–427. 1932.*

[10] Hartley, C. Damping-off of coniferous seedlings. *Science,* **36**: *683–684. 1912.*

[11] Day, L. H. Zinc chloride treatment for pear blight cankers. *California Agr. Ext. Serv. Circ. No. 45. 1930.*

soluble salts. Later tests demonstrated that the difference between the zinc oxide and the soluble salts was due to lack of penetration by the insoluble zinc oxide into the soil. While an application to the surface of the soil gave some control of the post-emergence phase of the disease, the chemical never penetrated deeply enough to prevent pre-emergence damping-off, so that the stand was thin.

TABLE 1.— EFFECT OF SOLUBLE AND INSOLUBLE ZINC COMPOUNDS AS SOIL TREATMENTS ON DAMPING-OFF OF TOMATOES, 700 SEEDS PLANTED NOVEMBER 5, 1931.

TREATMENT	DOSAGE PER SQ. FT., GRAMS	PLANTS EMERGED		PERCENTAGE DISEASED IN 200	REMARKS
		Number	Per cent		
Check (untreated).	.....	216	30.9	96.5	
Check (untreated).	.....	228	32.6	98.5	
Average.....	.....	....	31.7	97.5	
Zinc oxide.....	10	383	54.7	44.5	Pre-emergence disease control inadequate because of poor penetration into soil
Zinc oxide.....	10	411	58.7	26.5	
Average.....	.....	....	56.7	35.5	
Zinc sulfate.....	10	523	74.7	22.5	
Zinc sulfate.....	10	550	78.6	26.0	
Average.....	.....	....	76.7	24.3	
Zinc chloride.....	10	524	74.9	32.5	Delayed emergence; plants burned off; indistinguishable from damping-off
Zinc chloride.....	10	522	74.6	49.0	
Average.....	.....	....	74.8	40.8	
Zinc chloride.....	5	595	85.0	26.5	This dosage better than 10 grams per sq. ft.
Zinc chloride.....	5	603	86.1	34.0	
Average.....	.....	....	85.6	30.3	

This fact emphasizes further the necessity for distinguishing between the pre-emergence and post-emergence phases of the disease and shows that both are integral parts of the damping-off picture and that neither can be ignored safely when devising chemical control measures. Seed treatment with red copper oxide, for instance,

gives control of the pre-emergence phase, while soil treatment with zinc oxide gives control of the post-emergence phase, but neither can be considered wholly adequate by itself. In the final analysis, these treatments should be considered as supplementary to each other.

ZINC OXIDE AS A SUPPLEMENTARY SURFACE TREATMENT

The photographs given in Fig. 1 show clearly that the zinc oxide soil treatment must be considered supplementary to seed treatment, that by itself it is of little practical value and that if only one treatment is to be used, the seed treatment is much to be preferred. These are pictures from a typical series of tomatoes on which were tried the various combinations of red copper oxide seed treatment and zinc oxide soil treatment. In order to bring out in the pictures the individual plants damped-off above ground, a large pea seed was placed on the soil beside each. Thus a large number of pea seeds indicates a large amount of post-emergence damping-off. A thin stand, of course, indicates a large amount of pre-emergence damping-off. Flat A was given the combination seed and soil surface treatment. The red copper oxide on the seed protected the plants before they emerged and the zinc oxide on the soil protected them afterwards. Flat B received the soil treatment but no seed treatment. As a result the seedlings were killed before they were able to emerge and the stand was thin, altho those that did get thru to the light were protected fairly well as shown by the few peas. Flat C received the seed treatment, but no soil surface treatment. Seedlings emerged satisfactorily because they were protected from decay by the red copper oxide. They damped-off to some extent later, however, because there was no "galvanizing" treatment on the soil surface. Under other conditions this treatment has permitted much more damping-off. Flat D received no treatment whatsoever, so that the plants damped-off both before and after they emerged.

Data from many experiments with tomato as the index plant, which appear in Table 2, show clearly the interdependence of the seed and soil treatments for damping-off control. The combination treatment not only gave control of the post-emergence disease, but also gave slightly better stands than the seed treatment alone. This apparent stand increase may have been due in part, at least, to a loss of seedlings from post-emergence disease before the data were taken in the seed treatment flats.

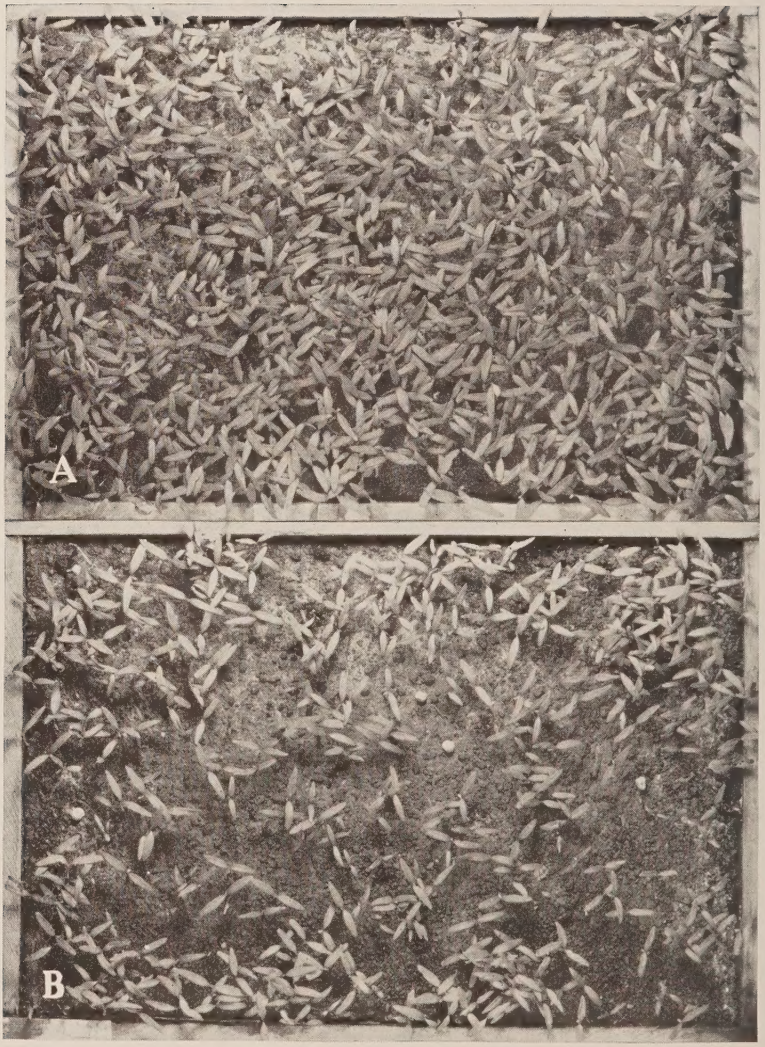
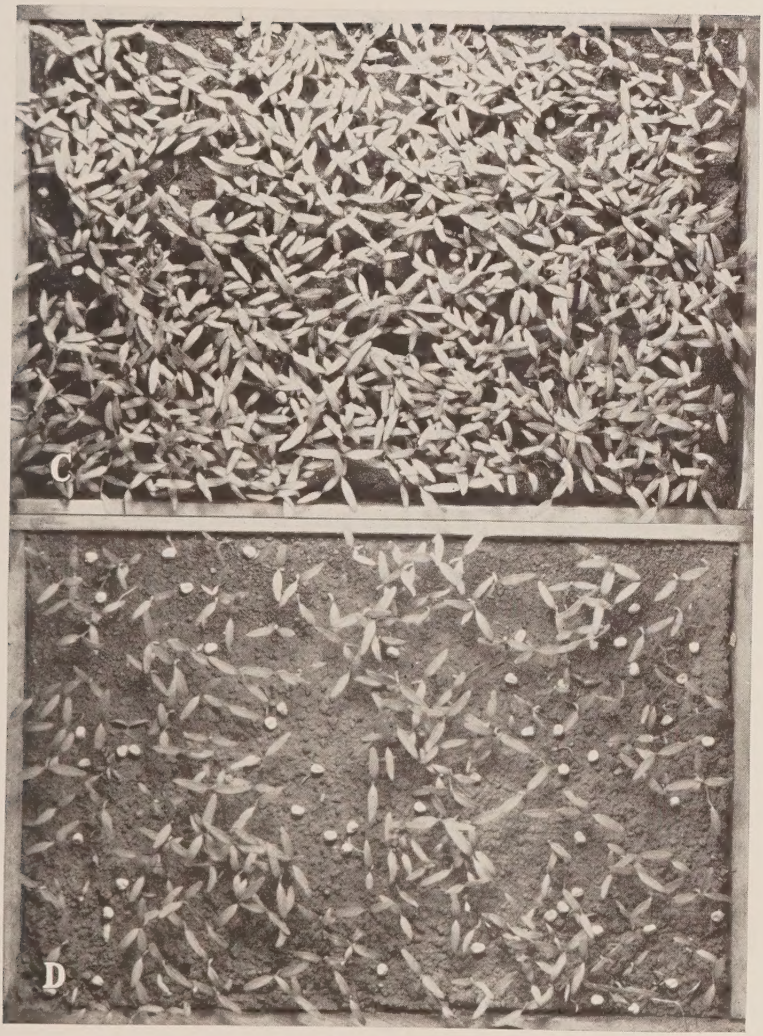


FIG. 1.—ZINC OXIDE SOIL TREATMENT MUST BE CONSIDERED SUPPLEMENTARY DISEASE. THE PEA SEEDS REPRE-

A, Red copper oxide on seed; zinc oxide on soil surface. Both phases of damping-off controlled.

B, No treatment on the seed; zinc oxide on soil surface. Only post-emergence disease controlled.



TO A SEED TREATMENT, BECAUSE ALONE IT WILL NOT CONTROL PRE-EMERGENCE SENT POST-EMERGENCE DISEASE.

C, Red copper oxide on seed; no treatment on soil surface. Only pre-emergence disease controlled.

D, No treatment on the seed; no treatment on soil surface. Neither phase of damping-off controlled.

TABLE 2.— EFFECT OF SEED TREATMENT WITH RED COPPER OXIDE OR ZINC OXIDE AND SOIL TREATMENT WITH ZINC OXIDE ON CONTROL OF PRE-EMERGENCE AND POST-EMERGENCE DAMPING-OFF OF TOMATOES IN SOIL TREATED AT PLANTING TIME.*

DATE	CHECK (UNTREATED)				SEED TREATMENT ONLY †				SEED AND SOIL TREATMENT †			
	Emerged		Damped-off		Emerged		Damped-off		Emerged		Damped-off	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Nov. 1, 1932	391	24.5	104	26.9	**1,148**	**71.8**	**245**	**21.6**	**1,140**	**71.3**	**52**	**4.6**
Nov. 14, 1932	235	14.7	82	38.6	**936**	**58.5**	**124**	**13.3**	**1,095**	**68.4**	**30**	**2.8**
Nov. 29, 1932	1,071	66.9	275	25.7	**1,280**	**80.0**	**172**	**13.4**	**1,333**	**83.4**	**36**	**2.7**
Dec. 19, 1932	943	58.9	237	25.1	**1,336**	**83.5**	**157**	**11.7**	**1,393**	**87.1**	**32**	**2.3**
	.....	.....	.....	.....	1,273	79.6	156	12.3	1,377	86.0	73	5.3
Jan. 14, 1933	664	41.5	175	26.4	.....	.....	.....	.....	**1,464**	**91.5**	**25**	**1.8**
	.....	.....	.....	.....	.....	.....	.....	.....	1,473	92.1	39	2.7
Jan. 18, 1933	880	62.9	135	15.5	.....	.....	.....	.....	**1,106**	**79.0**	**28**	**2.6**
	.....	.....	.....	.....	.....	.....	.....	.....	1,104	78.9	25	2.3
Feb. 10, 1934	1,045	76.2	131	12.6	.....	.....	.....	.....	**1,095**	**79.8**	**13**	**1.2**
Average	.....	49.4	.....	25.8	.....	74.7	.....	14.5	.....	81.8	.....	2.83

* Figures are averages from duplicate tests.
† Figures in bold face indicate seed treated with red copper oxide; those in roman indicate seed treated with zinc oxide.

TABLE 3.— EFFECT OF DEPTH OF PLANTING ON CONTROL OF DAMPING-OFF OF SPINACH BY A SOIL SURFACE TREATMENT WITH ZINC OXIDE ALONE AND IN COMBINATION WITH A RED COPPER OXIDE SEED TREATMENT.

DEPTH PLANTED, INCH	TREATMENT	PERCENTAGE DAMPED-OFF ON NOV.						NUMBER UP NOV. 24	EMERGED		TOTAL PERCENTAGE DAMPED-OFF
		17	18	20	21	23	24		Total number up	Per cent	
⅛	Surface only	10.8	5.4	2.9	3.3	1.8	2.6	528	722	62.8	26.9
	Combination	0.04	0.05	0.09	0.11	0.10	0.12	929	1,000	87.0	5.1
¼	Surface only	14.1	5.8	4.4	3.4	2.4	0.7	522	757	65.8	31.0
	Combination	1.1	1.1	1.2	0.9	0.7	0.9	893	948	82.4	5.8
½	Surface only	36.0	10.7	7.0	6.5	3.0	3.0	146	431	37.5	66.1
	Combination	8.6	14.8	11.9	7.9	7.4	2.3	374	795	69.1	53.0
¾	Surface only	45.5	20.3	7.6	4.5	1.0	4.6	47	290	25.2	83.8
	Combination	9.4	18.1	13.4	10.1	9.0	2.5	290	774	67.3	62.5
1	Surface only	29.9	28.5	20.0	6.5	2.5	2.8	35	355	30.9	90.1
	Combination	6.0	12.7	16.7	10.7	11.4	5.9	294	795	69.1	63.5

A simple depth of planting experiment lends further evidence to the theory that the zinc oxide surface treatment must be considered supplementary to a seed treatment. Spinach seed untreated and treated with red copper oxide was planted at different depths under a soil surface that was covered at planting time with zinc oxide at the rate of 10 grams per square foot. The data in Table 3 show that the zinc oxide surface treatment failed to control the pre-emergence phase of the disease completely even when the seeds were covered as shallow as ⅛ inch. Moreover, the post-emergence disease in the flats with only a surface treatment increased with depth of planting, *even tho the soil surface was covered with zinc oxide,* proving that many plants that damp-off after emergence

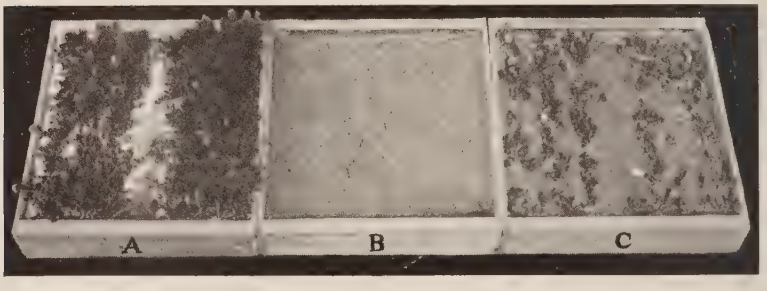


Fig. 2.—Damping-off of Romaine Lettuce Controlled by Combination Treatment.

Three flats were sown impartially in Lewis Avery's greenhouse near Syracuse with lettuce seed from the same packet. The seed planted in the left half of flats A and C was treated with red copper oxide; that planted in the right half with zinc oxide. In addition, the soil surface in flat A was treated with zinc oxide at planting time. Flat C received no soil treatment. In flat B, neither the seed nor the soil were treated in any way.

really become diseased beforehand. Hence, the pre-emergence disease must be controlled by a seed treatment if the full benefit from the zinc oxide surface treatment is to be obtained. With the combination treatment, seeds could be planted as deep as ¼ inch and still be well protected from both phases of damping-off. If they were planted as deep as ½ inch or deeper, however, damping-off control was not adequate. This test demonstrates the necessity of regulating planting depth when studying damping-off.

A grower near Syracuse was having difficulty with his romaine lettuce seed which he suspected to be poor. Some of this seed

was treated with a slight excess of red copper oxide and some with zinc oxide and sown impartially by the grower himself. A photograph of the results appears in Fig. 2. Six rows of seed were sown in each of three flats, one of which received no treatment of any kind. In the other two flats, half of the six rows were sown with red-copper-oxide treated seed and half with zinc-oxide-treated seed. One of the two flats planted with treated seed received in addition an application at planting time of ⅔ ounce (20 grams) of zinc oxide per square foot. The strong emergence and small amount of damping-off in the treated flats shown in Fig. 2 indicate that the poor stands had not been due to poor seed, but rather to damping-off instead.

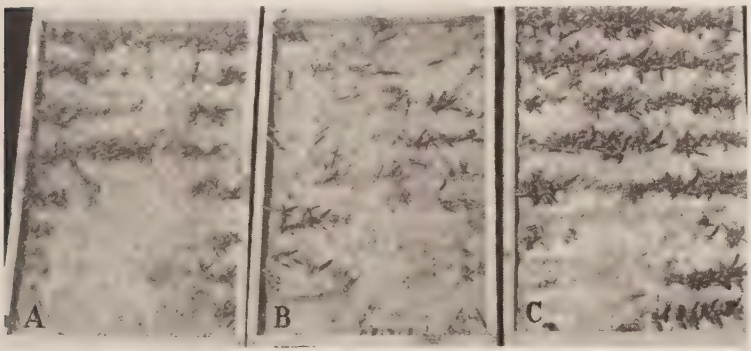


Fig. 3.— Disturbing the "Galvanizing" Layer Permits Damping-off Corrosion in Pepper Stand.

B, No treatment. A, Seed only treated with red copper oxide. Stand increased but post-emergence disease serious. C, Seed treated with red copper oxide and soil also treated with zinc oxide. Stand increased and post-emergence disease stopped until soil cultivated, then a large area of plants dropped out because they were no longer protected.

An experiment near Schenectady, shown in Fig. 3, demonstrated strikingly the "galvanizing" effect of the zinc oxide. The combination seed and soil treatment gave early control of both phases of the disease as shown by the good stand. Cultivation shortly after emergence destroyed the "galvanizing" layer around the plants and permitted the fungus to get at the plants, after which it killed those in a large, circular spot. This appears in the lower half of Flat C in Fig. 3.

ZINC OXIDE MIXED WITH COVERING SOIL

There is the possibility that mixing zinc oxide with the surface covering of soil would control both phases of the disease more simply than a combination treatment, since theoretically the chemical should then permeate the layer of soil where the disease attacks. Several tests, data on one of which is shown in Table 4, showed that the mixing method is not as satisfactory as the combination seed and soil treatment. The larger quantities of the chemical injured the plants and the smaller quantities failed to stop the disease, probably because not all the seedlings were in contact with the chemical.

ZINC OXIDE APPLIED TO TRANSPLANTS

An essential preliminary to successful control of damping-off of transplants is that the seedlings to be transplanted *must be healthy*. Attempting to stop damping-off of transplants is futile unless healthy seedlings are available. Thus the control of damping-off in the seedling tray is of utmost importance. For that reason transplants from treated seed frequently survive more often than transplants from untreated seed.

Even tho healthy seedlings are available, however, damping-off is more difficult to control in transplants than in seedlings. Chemicals may be applied to the soil in the seedling tray before the plants emerge to avoid foliage injury, but in the case of transplants the chemical must be applied to the foliage as well as to the soil. Hence the chemical chosen must be relatively non-injurious to leaves and still must be toxic enough to the parasites to control damping-off. Observations on eggplant, lettuce, pepper, and tomato indicate that zinc oxide is such a chemical. It gave commercial control of the disease and did not seem to be excessively toxic to the plants. Some growers preferred a little scorching from zinc oxide to damping-off, especially early in the season when injury seems less severe and the disease more prevalent than later.

Under Geneva conditions foliage of the following plants was not scorched by ⅔ ounce (20 grams) of zinc oxide per square foot: Calendula, centaurea, chicory, cosmos, dahlia, eggplant, hollyhock, lettuce, nasturtium, parsley, pepper, spinach, and tomato. The chemical scorched somewhat the following plants: Dianthus, gypsophila, petunia, *Phlox Drummondii*, poppy, and pyrethrum. It seemed

to "stimulate" or accelerate the growth of lettuce in commercial greenhouses near Geneva and Syracuse. In 1934 it gave satisfactory disease control without excessive injury to such plants as tomato, eggplant, pepper, celery, snapdragon, and beet in Niagara County; for pepper, tomato, eggplant, and salvia in Schenectady County; and for wallflower in Erie County. There seemed to be some injury to celery on muck in Wayne County, but not in Niagara County. It

TABLE 4.—COMPARISON BETWEEN COMBINATION SEED AND SOIL TREATMENT AND MIXING THE ZINC OXIDE WITH THE COVERING SOIL FOR CONTROLLING DAMPING-OFF OF SPINACH.

TREATMENT	EMERGENCE		DAMPING-OFF	
	Number	Per cent	Number	Per cent
Check (untreated)	368	32.0	273	40.1
Check (untreated)	379	33.0	341	90.0
Average	.....	32.5	.....	65.0
Combination seed-soil	699	60.8	103	14.7
Combination seed-soil	878	76.4	90	10.3
Average	.....	68.6	.....	12.5
20 grams zinc oxide mixed with surface layer	480	41.7	295	61.5
20 grams zinc oxide mixed with surface layer	724	62.9	247	34.1
Average	.....	52.3	.....	47.8
40 grams zinc oxide mixed with surface layer	784	68.2	301	38.4
40 grams zinc oxide mixed with surface layer	830	72.3	310	37.3
Average	.....	70.3	.....	37.9
80 grams zinc oxide mixed with surface layer	797	69.3	395	49.6
80 grams zinc oxide mixed with surface layer	720	62.6	380	52.8
Average	.....	66.0	.....	51.2

was said to control damping-off on rhododendron cuttings near Rochester, but it injured rhododendron seedlings in a greenhouse near Buffalo. It also injured lettuce, pepper, and cauliflower in houses near Buffalo.

ZINC OXIDE AS A SEED TREATMENT

IN COMPARISON WITH RED COPPER OXIDE

The usefulness of zinc oxide as a soil treatment suggested that it can be used also as a seed treatment. Data obtained on several sorts of seeds treated at the dosage that is recommended and sown in the Station greenhouses appear in Table 5. Altho the average difference may not be great in all cases between zinc oxide and red copper oxide, the former appears less effective than the latter in Geneva soil for tomato, spinach, eggplant, pea, lima bean, beet and cucumber. The picture of lettuce in Fig. 2, however, indicates as growers in the vicinity of Syracuse contend, that zinc oxide is more effective as a seed treatment than red copper oxide. The same situation seems to obtain in Schenectady County. These facts justify the point of view that damping-off is a specific problem, that no one chemical can give perfect results, and that knowledge of more chemicals is needed.

FIG. 4.—ZINC OXIDE SEED TREATMENT (A) LESS EFFECTIVE THAN RED COPPER OXIDE (B) ON PEAS.

Dosage ¼ per cent by weight in each case. 100 seeds sown per flat. Compare with Figs. 5 and 6.

Since legumes are known to be injured sometimes by red copper oxide,[11] several of these were tried with zinc oxide. Peas were

[11] See Bulletin No. 643, page 16, of this Station.

not benefited, as shown in Table 5 and in Fig. 4. Altho the untreated flat is not shown in the picture, the stand was much the same as that in the zinc oxide flat. Lima beans (Table 5) also were not benefited by zinc oxide. On the other hand, both clover and alfalfa were helped more by the zinc oxide than by the red copper oxide, as

TABLE 5.— COMPARING ZINC OXIDE WITH RED COPPER OXIDE AS A SEED TREATMENT FOR VARIOUS PLANTS.

DATE PLANTED	CHECK (UNTREATED)			RED COPPER OXIDE			ZINC OXIDE		
	Emerged		Damped-off	Emerged		Damped-off	Emerged		Damped-off
	Number*	Per cent	Per cent	Number*	Per cent	Per cent	Number*	Per cent	Per cent
Tomatoes									
Nov. 11, 1931	750	53.5	52.8†	1,340	95.7	14.0†	1,093	78.0	19.8†
Jan. 19, 1932	855	61.1	45.0	1,174	84.2	21.0	1,277	91.3	13.0
Feb. 9, 1932	1,055	75.4	49.3	1,278	81.3	15.3	1,152‡	82.3	24.8
Nov. 1, 1932	391	24.5	26.9	1,148	71.8	21.6	1,169	73.1	6.9
Nov. 16, 1932	235	14.7	38.6	946	58.5	13.3	885	55.3	11.6
Dec. 19, 1932	943	58.9	25.1	1,336	83.5	11.8	1,273	79.6	12.3
Feb. 7, 1933	738	53.9	.....	1,067	77.8	.....	1,073	78.3	.....
Feb. 6, 1934	817	51.6	16.3	1,130	71.3	.....	1,093	69.0	.....
Average	.....	49.2	36.3	.....	78.0	16.2	.....	75.9	14.8
Beet									
Jan. 13, 1933	67.7	67.7	13.3	192	.....	0.4	118	.....	4.5
Cucumber									
Feb. 6, 1934	28	14.0	21.4	187	93.5	6.9	170	85.0	3.5
Mar. 6, 1934	22	11.0	9.1	178	89.0	3.4	175	87.5	4.6
Eggplant									
Nov. 6, 1931	633	23.4	54.3	1,789	66.2	30.0	1,428	52.9	38.8
Mar. 22, 1932	568	43.7	36.3	756	58.1	25.8	737‡	56.7	22.8
Feb. 6, 1934	604	.....	15.7	721	.....	5.8	645	.....	6.2
Lima Bean									
April 2, 1934	4	8.0	.....	19	38.0	.....	14	28.0	.....
Pea§									
April 1, 1932	3	0.7	.....	63	58.6	.....	20‡	18.6	.....
Mar. 6, 1934	15	15.0	.....	83	83.0	.....	37	37.0	.....
Feb. 6, 1934	18	18.0	.....	62	62.0	.....	36	36.0	.....
April 2, 1934	35	35.0	.....	84	84.0	.....	68	68.0	.....
Average	.....	17.2	.....	.....	71.9	.....	.....	39.9	.....
Pepper									
Nov. 6, 1931	439	33.8	34.8	1,011	77.8	11.3	864	66.4	18.0
Radish									
Feb. 6, 1934	581	62.3	24.8	516	55.3	17.8	550	58.9	16.5
Spinach									
Mar. 23, 1933	212	.....	58.9	426	.....	26.2	387‖	.....	.....
Feb. 6, 1934	504	.....	63.1	834	.....	42.8	818	.....	39.2
Mar. 6, 1934	96	.....	65.6	176	.....	8.0	161	.....	29.2

* Equal number, volume, or weight of seed sown per flat.
† Per cent in 200 plants.
‡ Zinc hydroxide used instead of zinc oxide.
§ Peas grown in greenhouse.
‖ Powdered zinc used instead of zinc oxide.

shown in Fig. 5. Perhaps clover seedlings in New York State would "catch" more satisfactorily if the seed were treated with zinc oxide.

Fig. 5.—Zinc Oxide Seed Treatment (B) More Effective Than Red Copper Oxide (A) or No Treatment (C) on Red Clover.

Dosage 2½ per cent by weight in each case. Equal weight of seeds sown in each flat. Much the same result was obtained with alfalfa. Compare with Fig. 4.

IN COMPARISON WITH SEMESAN

Since a large tonnage of cabbage seed in the State is now dusted with Semesan after a hot water treatment, and since the crucifers are liable to red copper oxide injury, hot-water-treated cabbage seed was treated with zinc oxide, as shown in Table 6. These data, as well as the photograph shown in Fig. 6, indicate that zinc oxide is promising as a damping-off treatment for cabbage seed.

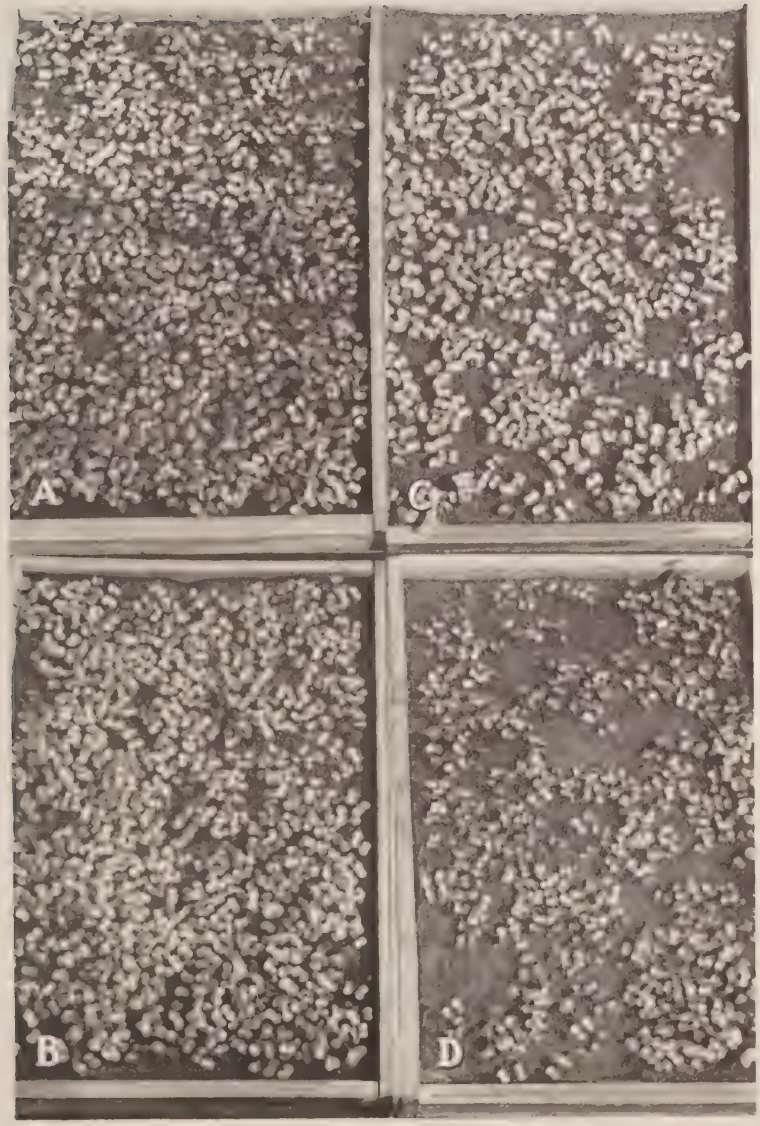


FIG. 6.—ZINC OXIDE COMPARES FAVORABLY WITH SEMESAN AS A SEED TREATMENT FOR CABBAGE AND IS SUPERIOR TO RED COPPER OXIDE.

The seed treatments are as follows: A, Zinc oxide; B, Semesan; C, Red copper oxide; and D, Untreated.

Table 6.— Comparison Between Zinc Oxide, Red Copper Oxide, and Semesan as Seed Treatments for Cabbage Seed.*

Date planted	Check (untreated)	Zinc oxide	Red copper oxide	Semesan
	Number emerged	Number emerged	Number emerged	Number emerged
Mar. 19, 1934	514	825	551	823
April 21, 1934	320	753	533	833

* See Fig. 6.

OTHER ZINC COMPOUNDS AS SEED TREATMENTS

Results with other zinc compounds as seed treatments are reported in Table 7 where the emergence figures alone are given because these are known to be significant for rating such compounds. Red copper oxide was included in each test for the sake of comparison.

It is obvious that zinc stearate and zinc gluconate are nearly worthless as fungicides. Zinc chromate stands out in many cases above the others. This material suggested itself for further trial as a seed treatment fungicide and was tested extensively on pea seed as a possible substitute for red copper oxide, but it was not as effective and occasionally was more injurious. It is interesting that it was more effective on peas than zinc oxide, however. The results with powdered zinc appearing in Table 7 are interesting and should be followed up.

DISCUSSION

During this entire damping-off investigation the need has been felt for a durable soil fungicide, a soil protectant, a "galvanizing" chemical, so to speak. Other chemicals are available for that purpose, it is true, but each has its drawbacks.

Zinc oxide seems to find a place in the pharmacopoeia of plant pathology for that purpose. It has long been used in human medicine as a surface application for cuts and fungous diseases of the skin, altho some medical men feel that its fungicidal value is small. They have considered it more as a drying agent. There is good evidence, however, of its fungicidal action in damping-off control.

Zinc oxide applied on the surface apparently penetrates but little thru the soil. This is to its advantage in some ways, because it is less likely to be injurious to roots as it certainly is when mixed

TABLE 7.— COMPARING DIFFERENT ZINC COMPOUNDS AS SEED TREATMENTS WITH RED COPPER OXIDE, DATA FOR EACH TEST INDICATING AVERAGE PERCENTAGE EMERGENCE FROM DUPLICATE FLATS.

DATE PLANTED	RED COPPER OXIDE	ZINC COMPOUNDS										CHECK (UNTREATED)
		Oxide	Hydroxide	Carbonate	Chromate	Gluconate	Oxalate	Powdered	Stearate	Sulfate	Sulfide	
Eggplant												
April 4, 1932	.....	53.1	56.7	56.4	55.3	.....	56.0	.....	.....	47.2	45.5	43.7
Spinach*												
Mar. 23, 1933	426	.....	.....	.....	339	.....	.....	387	.....	.....	.....	212
Tomato												
Nov. 11, 1931	95.7	78.0	85.5	55.8	90.1	.....	80.5	.....	33.9	81.7	.....	53.5
Jan. 19, 1932	84.2	91.3	86.9	79.8	87.1	.....	84.9	.....	62.7	85.7	.....	61.1
Feb. 9, 1932	81.3	.....	82.3	.....	89.0	.....	.....	.....	.....	90.0	76.5	75.4
Mar. 10, 1932	77.5	.....	63.3	.....	82.6	.....	.....	.....	.....	75.9	70.1	70.1
Nov. 1, 1932	71.8	73.1	64.5	.....	56.8	29.0	.....	.....	.....	.....	.....	24.5
Nov. 16, 1932	58.5	55.3	.....	.....	56.4	54.7	.....	.....	.....	.....	.....	14.7

* Number seeds emerged from 5 grams instead of percentage.

intimately with soil. Since it does fail to penetrate the soil, it fails to stop the fungi there that are responsible for pre-emergence damping-off. This means that a surface application must be supplemented by a seed protectant. It means further that for satisfactory control of damping-off seeds should not be planted deeper than ¼ inch.

Results with zinc oxide serve as further evidence that the damping-off problem is specific in a narrow sense. Unquestionably, red copper oxide is more effective generally than zinc oxide as a seed treatment in the Station greenhouses; but zinc oxide is just as surely more effective near Syracuse. Zinc oxide also seems to be preferred in Schenectady County. These points demonstrate geographical variability. Using different plants even in the same flat will show that zinc oxide is preferable for one plant and red copper oxide for another. This indicates plant variability.

Few real data are available to explain this difference but, speculatively, four possibilities must be considered. First, there are differences in the fungous complex responsible for the damping-off. *Rhizoctonia* may be predominant in some places, *Pythium* in others, and *Fusarium* in others. If Hemmi's[12] results may be applied generally, high temperature in the house probably favors *Pythium* and low temperature favors *Rhizoctonia*. Second, fungi undoubtedly differ in their sensitivity to chemicals. Third, plants differ in their susceptibility to fungi. Fourth, plants differ in their sensitivity to chemicals. Since many soils carry numerous damping-off organisms and are used under many varying conditions, it is certain that damping-off control with chemicals must become a specific problem. The end is not yet in sight.

USING ZINC OXIDE IN PRACTICE

The use of zinc oxide can now be proposed safely because growers have already stamped it with their approval. A group of men near Schenectady used several hundred pounds in the spring of 1934. Niagara and Onondaga County growers also made satisfactory use of it the same season.

[12] Hemmi, T. On the relation of temperature to the damping-off of garden-cress seedlings by *Pythium debaryanum* and *Corticium vagum*. *Phytopath.*, 13: *273–282. 1923.*

The points to be considered in using zinc oxide will be listed below:

1. Zinc oxide is not intended to supplant the red copper oxide[13] seed treatment for damping-off control because that method has already demonstrated its value. Zinc oxide is being proposed as a treatment for the surface of the soil to "galvanize" it and prevent the spread of above-ground damping-off. In this respect it must be considered as a supplement to the seed treatment method for disease control in those cases where the latter is insufficient.

2. Used as a soil treatment, it has given satisfactory damping-off control of beet, cauliflower, celery, cucumber, eggplant, lettuce, pepper, petunia, salvia, snapdragon, spinach, and tomato. Undoubtedly other plants also would be benefited but these have not been tested here.

3. Do not sow seeds deeper than ¼ inch for best results.

4. If it is to be used in the seedling tray, apply the chemical before the plants emerge, preferably at planting time, to assure best results and to avoid any possibility of injury. After the plants emerge it is wise to settle the soil and zinc oxide around the stems by a gentle stream of water from the sprinkler.

5. Apply sufficient chemical to the surface of the soil to give a smooth, white layer. This requires about ½ to one ounce per square foot.

6. Most growers prefer the dry powder, applying it with a flour mixer, a cheesecloth bag, or a large salt shaker. Some use a large can with the lid punched full of holes. For large areas, a hand duster opened to its widest capacity may be employed.

7. Other growers prefer to suspend the powder in water and apply with a sprinkling pot, thinking that they get less injury.

8. Do not disturb the layer of chemical, because its effect depends largely upon being always in contact with the plants.

9. When used on transplants, it may be applied immediately after transplanting, but probably it would be less injurious if applied after the plants straighten up. The excess should be brushed from the leaves and rinsed into the soil. Use the same quantities as for the seedling tray.

Zinc oxide has not given injury in certain tests when applied to the following transplants: Beets, calendula, celery, centaurea, chicory,

[13] See Bulletin No. 643 of this Station.

cosmos, dahlia, eggplant, hollyhock, lettuce, nasturtium, parsley, pepper, salvia, snapdragon, spinach, tomato, and wallflower. It did, however, under some conditions scorch celery, cauliflower, dianthus, gypsophila, lettuce, pepper, petunia, *Phlox Drummondii*, poppy, and pyrethrum.

10. Conditions responsible for injury are not well understood. Certainly the chemical should not be applied to plants on a hot or a sunny day. Evening applications are preferred. Perhaps there may be impurities in some grades of the material, but nothing is known yet about these.

11. Zinc oxide may be used also as a seed treatment instead of red copper oxide in some instances and is probably to be preferred for such plants as broccoli, brussel sprouts, cabbage, chinese cabbage, cauliflower, endive, kale, kohlrabi, lettuce, parsley, radish, and turnip. The seed should be shaken with it at the rate of two teaspoonsful per pound of seed. For large lots of seed a dosage of 1½ to 2 per cent by weight is satisfactory.

12. Zinc oxide is a relatively cheap compound. It should cost from 10 to 15 cents per pound in 200-pound lots, and probably not more than 25 cents per pound retail. Druggists handle it, but the price is excessive. It may be obtained from paint stores under the name "zinc white."

SUMMARY

1. Zinc oxide is proposed as a durable damping-off fungicide; primarily as a soil surface treatment supplementary to the seed treatment method for damping-off control discussed in Bul. No. 643 of this station.

2. Zinc chloride and zinc sulfate are too injurious to plants to be safe generally when applied to soil.

3. Zinc oxide penetrates into the soil so poorly that seeds should not be sown deeper than ¼ inch; otherwise disease control will be unsatisfactory.

4. The layer of chemical over the surface should not be disturbed until danger of damping-off is past.

5. Zinc oxide cannot be mixed with the surface soil to control damping-off with one operation, because a quantity sufficient for disease control is injurious to the plants.

6. If applied dry and then brushed from the foliage before rinsing into the soil, zinc oxide may be used satisfactorily for damping-off in transplants, at least in some localities. It should be applied on cool, cloudy days or in late afternoon.

7. Zinc oxide may be used as a seed treatment, but probably is not as generally effective as red copper oxide. For some plants, particularly crucifers and lettuce, and in some localities, it is even more effective. On cabbage at Geneva it compared favorably with Semesan as a seed treatment.